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A novel surface micromachining process to fabricate AlN unimorph suspensions and its application for RF resonators

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Abstract

A novel surface micromachining process is reported for aluminum nitride (AlN) thin films to fabricate piezoelectric unimorph suspension devices for micro actuator applications. Wet anisotropic etching of AlN thin film is used with a Cr metal mask layer in the microfabrication process. Tetra methyl ammonium hydroxide (TMAH) of 25 wt.% solution is used as an etching solution for the AlN thin films. Polysilicon is used as a structural layer. Highly *c*-axis oriented AlN thin films are deposited by RF reactive sputtering. Thin layers of chromium on either side of the AlN are used as top and bottom electrodes and also as a mask to etch the AlN and polysilicon layers. The fabricated suspended unimorph structures are tested for scattering parameters using a vector network analyzer. Results show resonant frequencies of devices above 1.7 GHz with an effective electromechanical coupling factor, $K^2_{\text{eff}} \approx 1.7\%$.

Keywords: Aluminum nitride (AlN); Wet anisotropic etching; Piezoelectric unimorph suspension; Thin film bulk acoustic resonator (TFBAR)

1. Introduction

Aluminum nitride (AlN) thin films are interesting in MEMS applications because of their piezoelectricity, high acoustic velocity and chemical stability at high temperatures. Surface micromachined AlN thin film piezoelectric microstructures find many applications in modern telecommunication devices in the form of resonators and filters. A sandwich of AlN thin film between two electrode layers forms a basic configuration of piezoelectric unimorph structures as shown in Fig. 1. Applying a cyclic electric field across this piezoelectric AlN capacitor results in the AlN thin film to expand and contract alternatively causing excitation of acoustic waves. It is also known that thin structural layers can be beneficial for certain applications such as thin film bulk acoustic resonators (TFBAR). The quality of AlN thin films is decisive for electromechanical coupling. AlN grown with (0 0 2) orientation perpendicular to the substrate is favourable for such piezoelectric device applications [1]. Methods such as MOCVD, MOVPE, PLD, RF sputtering, sublimation etc. are used in the literature [2–4] to grow AlN thin films on several substrates. RF reactive sputtering is one of the common methods used to deposit polycrystalline AlN thin films with preferentially (0 0 2) orientation perpendicular to the substrate in many kinds of substrates [5].

AlN thin film patterning, etch selectivity to the mask layer, compatibility with surface micromachining processes and minimum feature size of free-standing piezoelectric microstructure are key factors in the fabrication process. Wet patterning of AlN thin film using 0.6 wt.% tetra methyl ammonium hydroxide (TMAH) solution at room temperature and a Cr mask layer was already reported [6]. Fabrication of SOI-based AlN thin film suspended devices involving a very thick (15 μm) silicon structural layer was reported earlier [7]. Also, micromachined AlN piezoelectric resonating structures on SiO_2 structural layers with germanium as a sacrificial layer have been reported recently [8].

This paper reports on a new silicon-based surface micromachining process for integrating AlN thin films into a surface micromachining process and the fabrication of AlN unimorph suspension devices. These devices use SiO_2 as a sacrificial layer. Anisotropic wet etching of AlN using TMAH (25%) solution is used to pattern AlN microstructures using a Cr layer that simultaneously serves as top electrode. The dimensions of the active

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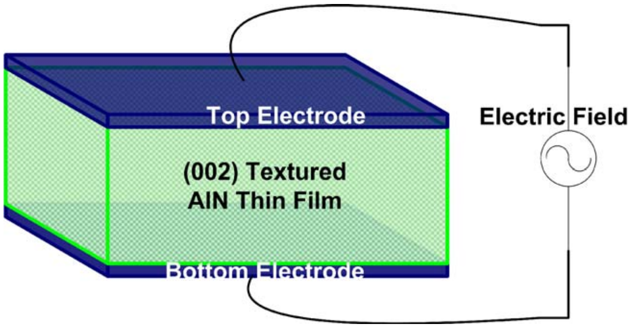

Fig. 1. A simple piezoelectric resonating beam with a sandwich of AlN between electrodes on polysilicon structural layer.

part of the device are (480 μm × 25 μm). The characteristics of these devices are measured using HP 8510C vector network analyzer (VNA) and an RF probe station.

2. Deposition of AlN thin films

Highly (0 0 2) textured AlN thin films are necessary for piezoelectric device applications. A Nordiko-2000 RF reactive sputtering machine has been used for the deposition process. The used deposition parameters for AlN thin films are shown in Table 1. For piezoelectric actuating structures, a stack of Cr/AlN/Cr layers was deposited in a single run without breaking the vacuum to ensure better adhesion of the Cr layers with AlN. The deposition was done at substrate temperatures <400 °C which is compatible with CMOS processes.

Fig. 2 shows X-ray diffraction ($\theta - 2\theta$) of a (0 0 2) oriented AlN thin film deposited on a Cr metal layer electrode. It indicates a high intensity (0 0 2) diffraction peak of AlN at 35.93° and its full width half maximum (FWHM) value was <3° as measured from rocking curve measurements. A narrow, sharp (0 0 2) diffraction peak indicates highly textured AlN grains with *c*-axis perpendicular to the substrate enabling good piezoelectric properties [1]. Fig. 3 shows an SEM image of dense columnar AlN thin film without trapped voids. The estimated grain size from XRD measurement by Scherrer's formula [9] is approximately 20–30 nm.

3. Anisotropic wet etching of AlN

AlN thin films on silicon substrates were used to study the etching behaviour of AlN thin films with Cr mask layers. The thickness of the mask layer is about 40–50 nm and it was found to be dense and uniform over the AlN thin films. The Cr layer was patterned first to make etch openings for AlN. It was done by a UV photolithography process with a mask having regular beam structures with a minimum width of 2 μm. A TMAH (25 wt.%) solution was used to etch AlN at room temperature without stirring the solution by external means. The etch depth was measured using a Dektak surface profiler and the etch rate was determined as 22 nm/min. The samples were investigated by scanning electron microscope (SEM) to study the etch profile under the Cr mask layer. A high etch selectivity of AlN with the Cr metal mask layer was found and it is shown in Fig. 4. The anisotropic etch profile of AlN under the Cr mask shows that the columnar layer of AlN thin films has been etched selectively with negligible lateral etching under the Cr mask layer (<2 nm/min).

Table 1
AlN deposition parameters

Parameters	Values
Base pressure (mbar)	$<3 \times 10^{-7}$
Substrate layer	Cr/polysi/SiO_2/Si
Sputter pressure (mbar)	3.3×10^{-3}
RF power (W)	350
Ar:N_2 flow rate (sccm)	8:3
Substrate temperature (°C)	360
Target-substrate distance (cm)	6

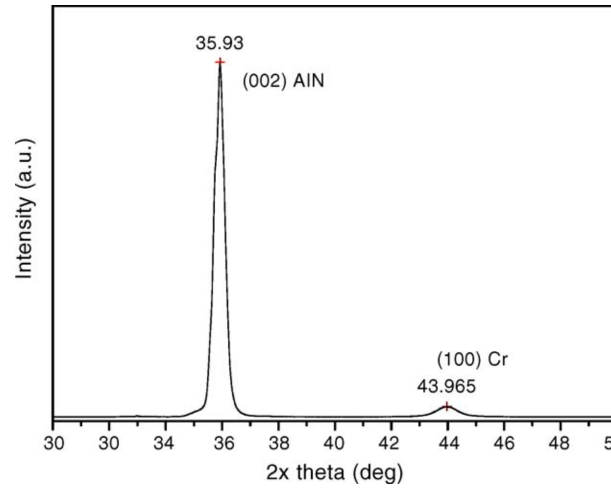

Fig. 2. X-ray diffractogram of (0 0 2) oriented AlN thin film on a Cr electrode layer.

4. Surface micromachining process

A schematic process description to fabricate AlN piezoelectric free standing microstructures is shown in Fig. 5. A stack of Cr/AlN/Cr layers forms an active area for piezoelectric actua-

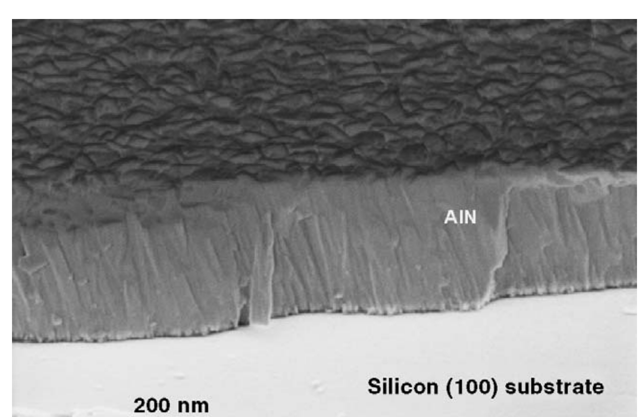

Fig. 3. RF reactive sputtered densely packed AlN thin film with (0 0 2) texture without voids.